Convergence Effects on Acceleration-driven Instability

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The Rayleigh-Taylor instability (RTI) [1] occurs at an interface between two fluids having different densities when the fluids are subject to acceleration (gravity) pointing from the heavy to the light. In many applications, RTI occurs in convergent geometries (e.g., cylindrical and spherical), which can include implosion and explosion. Examples are implosion in inertial confinement fusion (ICF), laser-induced launching of a flyer plate, stellar pulsations, and supernova explosions. Geometrical convergence or divergence introduces effects not present in Cartesian geometry. In literature, fundamental instability studies and high-resolution, high-accuracy computations of these flows in convergent geometries are scarce.

In many situations, perturbation growth in cylindrical or spherical geometry also includes a contribution from the interface movement, which is called the Bell-Plesset effect [2,3]. Both interface movement and acceleration-driven mechanisms concur and contribute to the perturbation growth towards turbulence.

There is a complex phenomenology associated with the evolution of the interfacial instability. If the initial perturbations are extremely small, the early growth of the instability is exponential with time. It can be analyzed using the linearized dynamic equations. When the amplitude of the perturbation grows, spikes and bubbles are formed due to nonlinear interactions among initial perturbations of different frequency. In the nonlinear growth stage, these spikes and bubbles compete, amalgamate, and entrail with each other. The motions become increasingly complex. Eventually, the flow becomes turbulent.

We have studied RTI-driven flow in cylindrical geometry in the linear early stage [4]. In parallel, we have developed an accurate direct numerical simulation (DNS) high-performance computation code to compute all stages of the instability growth, from early linear through weakly nonlinear and nonlinear growth to fully turbulent mixing.

The configurations examined in the linear stage include 3D cylindrical as well as 2D axisymmetric and circular unperturbed interfaces, which are compared with the Cartesian case with planar interface (PI). Focuses are on the effects of compressibility and geometrical convergence (or divergence) on the instability growth and the differences between implosion (gravity acting inward) and explosion (gravity acting outward). Compressibility can be characterized by two parameters: 1) static Mach number based on isothermal sound speed, and 2) ratio of specific heats, which in general have opposite influence, stabilization and destabilization, on the instability growth, similar to the Cartesian case [5]. Instability is found to grow faster in the 3D cylindrical case than in the Cartesian case in implosion but slower in explosion. In general, the difference between implosion and explosion is profound for the cylindrical cases but marginal for the planar interface. The influences of Atwood number, interface radius, and the transition between the 3D and 2D circular interface cases have also been considered.

We use the CFDNS code to perform direct numerical simulations of the compressible Navier-Stokes equations and species transport equations in cylindrical geometry for a Rayleigh-Taylor configuration. In addition to the parameters examined during the early stages, we are also interested in the influence of the equation of state and molecular transport properties (viscosity, heat conduction, and mass diffusion) on the instability development. Large-resolution numerical simulations are underway.

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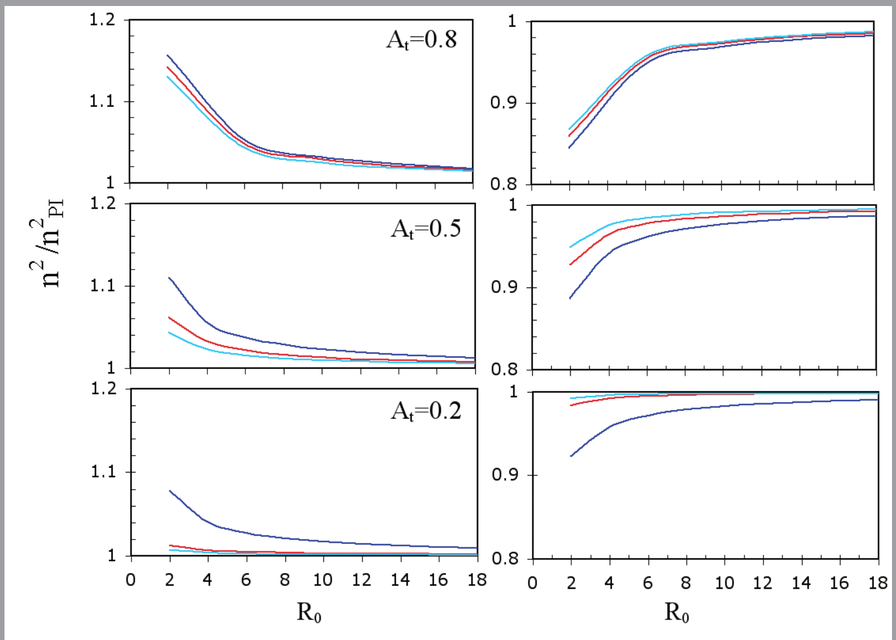

Fig. 1. Dependence of normalized growth rate of n on normalized position of the interface R_0. Left column: implosion; right column: explosion. The interface in implosion is less stable than in explosion. The differences between the cylindrical and Cartesian growth rates are largest at higher At numbers and small R_0.